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PERIGLACIAL INVOLUTIONS IN NORTHEASTERN ILLINOIS

BY

ROBERT P. SHARP

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PERIGLACIAL INVOLUTIONS IN NORTH-EASTERN ILLINOIS

ROBERT P. SHARP
University of Illinois

ABSTRACT

Certain beds of glaciofluvial sand, silt, and clay in the upper Illinois Valley are complexly deformed into variously shaped masses of silt and clay intruded into sand. Rounded forms and downward intrusions predominate. Individual structures are termed "involutions," and layers of deformed beds are called "involution layers"—equivalents of the *Brodelböden* and *Brodelzonen* of German writers. Deformation has not been observed below a depth of 12 feet and may extend within 3 or 4 feet of the surface. Single involution layers are from a few inches to 6 feet thick.

These involutions are attributed to intense differential freezing and thawing and to the development and melting of masses of ground ice. It is postulated that this occurred in a surficial layer above perennially frozen ground in an area peripheral to a glacier where periglacial (arctic) conditions prevailed. The involutions are believed to have been formed when the ice front lay 30–50 miles to the northeast and are dated as late Cary (late Middle Wisconsin).

INTRODUCTION

INTRODUCTORY STATEMENT

This article deals with only one of a large number of phenomena attributed to processes active under the arctic conditions prevailing in certain areas during the Pleistocene. Similar structures have been described from Europe, and the references cited in the following pages indicate the great amount of foreign work on this and closely related subjects. The features to be described were first observed in 1938 and have been studied at various intervals since.

HISTORICAL SUMMARY

Soil structures produced by frost action were recognized by Lovén in Spitzbergen in 1837.[1] Publications by Högbom,[2] K. Sapper,[3] and Axel Hamberg[4] and the 11th International Geological Congress expedition to Spitzbergen in 1910 subsequently aroused great interest in the work of frost at high latitudes and in high altitudes. As early as 1866 Rev. O. Fisher[5] suggested that certain features in England were "fossil" forms produced by frost action in Pleistocene-glacial or early postglacial time. Work on this subject became exceptionally vigorous after 1925 with the appearance of a great mass of German literature devoted to features in central Europe produced by frost action during the Pleistocene glaciation. This notable increase in periglacial studies was undoubtedly inspired partly by Paul Kessler's book[6]—a stimulating review of earlier work and an excellent compilation of periglacial concepts. Kirk Bryan[7] has been chiefly responsible for introduction of the periglacial concept into this country, and papers by him and by Ernst Antevs[8] have inspired other American studies.[9]

[1] Bertil Högbom, "Über die geologische Bedeutung des Frostes," *Bull. Geol. Inst. Univ. Upsala*, Vol. XII (1914), p. 309.

[2] *Ibid.*, pp. 257–398; "Beobachtungen aus Nordschweden über den Frost als geologischer Faktor," *ibid.*, Vol. XX (1926), pp. 243–79.

[3] "Erdfliessen und Strukturboden in polaren und subpolaren Gebieten," *Internat. Mitt. f. Bodenkunde* (1914).

[4] "Zur Kenntnis der Vorgänge im Erdboden beim Gefrieren und Auftauen sowie Bemerkungen über die erste Kristallization des Eises in Wasser," *Geol. Foren. i Stockholm Forhandl.*, Vol. XXXVII (1915), pp. 583–619.

[5] "On the Warp (of Mr. Trimmer)—Its Age and Probable Connexion with the Last Geological Events," *Quart. Jour. Geol. Soc. London*, Vol. XXII (1866), pp. 563–64.

[6] *Das eiszeitliche Klima, und seine geologischen Wirkungen im nicht vereisten Gebiet* (Stuttgart, 1925), pp. 1–210.

[7] "Glacial Climate in Non-glaciated Regions," *Amer. Jour. Sci.*, Vol. XVI (1928), pp. 162–64.

[8] *Alpine Zone of Mt. Washington Range* (Auburn, Me., 1932), pp. 1–118.

[9] C. S. Denny, "Periglacial Phenomena in Southern Connecticut," *Amer. Jour. Sci.*, Vol. XXXII (1936), pp. 322–42; "Glacial Geology of the Black Rock Forest," *Black Rock Forest, Bull. 8* (1938), pp. 1–70; "Stone-Rings on New Hampshire Mountains," *Amer. Jour. Sci.*, Vol. CCXXXVIII (1940), pp. 432–38; H. T. U. Smith, "Periglacial Landslide Topography of Canjilon Divide, Rio Arriba County, New Mexico," *Jour. Geol.*, Vol. XLIV (1936), pp. 836–60; W. E. Powers, "The Evidence of Wind Abrasion," *Jour. Geol.*, Vol. XLIV (1936), pp. 214–19; R. P. Goldthwait, "Geology of the Presidential Range," *N.H. Acad. Sci. Bull. 1* (1940), pp. 37–39.

TERMINOLOGY

W. Lozinski[10] appears to have been one of the first to use the term "periglacial," although neither he nor anyone else seems to have defined it. A periglacial environment is characterized by low temperatures, strong winds, and many fluctuations across the freezing-point at certain seasons. Various features resulting from processes promoted by such an environment are termed "periglacial." Unfortunately, this designation has been rather loosely used both for "fossil" and modern features and for ones not necessarily formed in an area peripheral to a glacier. The structures described herein are periglacial in the strictest sense, having been formed under the arctic conditions of an area peripheral to a glacier.

A term widely used in foreign circles for these features is *Brodelböden*, introduced by Karl Gripp[11] and subsequently used by others. There is no good English equivalent for *Brodelböden*, and its use is not advisable here because it is a foreign term and, furthermore, carries a certain implication of origin not subscribed to in this article. Bryan[12] suggests "involution" as a suitable term for the aimless deformation, distribution, and interpenetration of beds produced by frost action, and this is the terminology adopted.[13] According to Webster's *New International Dictionary*, an involution is something which is infolded, involved, intricate, or complicated. The structures within the deformed layer may be spoken of as "involutions," and any single structural unit separable from its associated forms may be termed an "involution." The deformed layer or zone is the "involution layer."

PHYSICAL RELATIONS

LOCATION

Involutions are exposed in the banks of a large strip coal mine, Pit 6 of the Northern Illinois Coal Corporation, $2\frac{1}{2}$ miles northeast

[10] "Über die mechanische Verwitterung der Sandsteine im gemässigten Klima," *Acad. sci. Cracovie, Cl. sc. math. et naturw. Bull. I.S* (1909); "Die periglaziale Fazies der mechanischen Verwitterung," *12th Internat. Geol. Cong., C. R.* (1910), p. 1039.

[11] "Beiträge zur Geologie von Spitzbergen," *Abh. naturw. Verein Hamburg*, Vol. XXI (1927). Pp. 38.

[12] Personal communication.

[13] See also Denny, "Periglacial Phenomena . . . .," *op. cit.*, p. 338; Kirk Bryan and L. L. Ray, "Geologic Antiquity of the Lindenmeier Site in Colorado," *Smithsonian Misc. Coll.*, Vol. XCIX (1940), p. 26.

of Coal City, Grundy County, northeastern Illinois (Fig. 1). This region is in the Morris Basin of the upper Illinois Valley, and the pit is at the eastern edge of the Morris quadrangle in Secs. 24 and 25, T. 33 N., R. 8 E. Constant opening of new exposures has afforded exceptionally favorable opportunity for successive observations.

The area between Coal City and the junction of the Kankakee and Des Plaines rivers to the north (Fig. 1) consists of a group of terrace-like flats separated by low, northward-facing escarpments, presumably ancient shorelines or river banks. Two of these escarpments appear just northeast of Coal City, the first at an elevation of 560 feet—the Lake Morris shoreline—and the second at the 540-foot contour—the Cryder Lake shoreline.[14] The coal pit has been dug into the flat about midway between these shorelines at an elevation close to 550 feet.

GEOLOGICAL SETTING

Geological relations at the coal pit are illustrated in Figures 1 and 2. A representative section consists of bedrock, a few feet of till, 10–30 feet of water-laid material, 2–3 feet of weathered sand and illuvial clay, and $1\frac{1}{2}$–3 feet of loamy soil.

The till is unweathered and blue-gray in color except near the north end of the pit where it contains considerable pink material. Its freshness indicates a probable Wisconsin age, and the location of the pit inside the Marseilles moraine and outside the Minooka (Fig. 1) suggests that at least some of the blue-gray till is Marseilles, although the pink material resembles Bloomington till. The water-laid deposits above contain the involutions and are moderately well-sorted, horizontal beds consisting of 85–95 per cent sand and 5–15 per cent clay, silt, and gravel. The gravels, except for a basal bed, are thin, discontinuous lenses containing roundstones of limestone, chert, and various crystalline rocks. The sand is chiefly clean, well-sorted, fine- to medium-sized quartz grains and locally contains small fragments of coal, armored clay pellets, and sparse roundstones up to 8 inches in diameter. The finer materials consist of sizes between clay and very fine sand and appear in thin interbedded layers that may be locally abundant but have no great lateral ex-

[14] H. E. Culver, "Geology and Mineral Resources of the Morris Quadrangle, Illinois," *Ill. State Geol. Surv. Bull. 43* (1923), pp. 180–81.

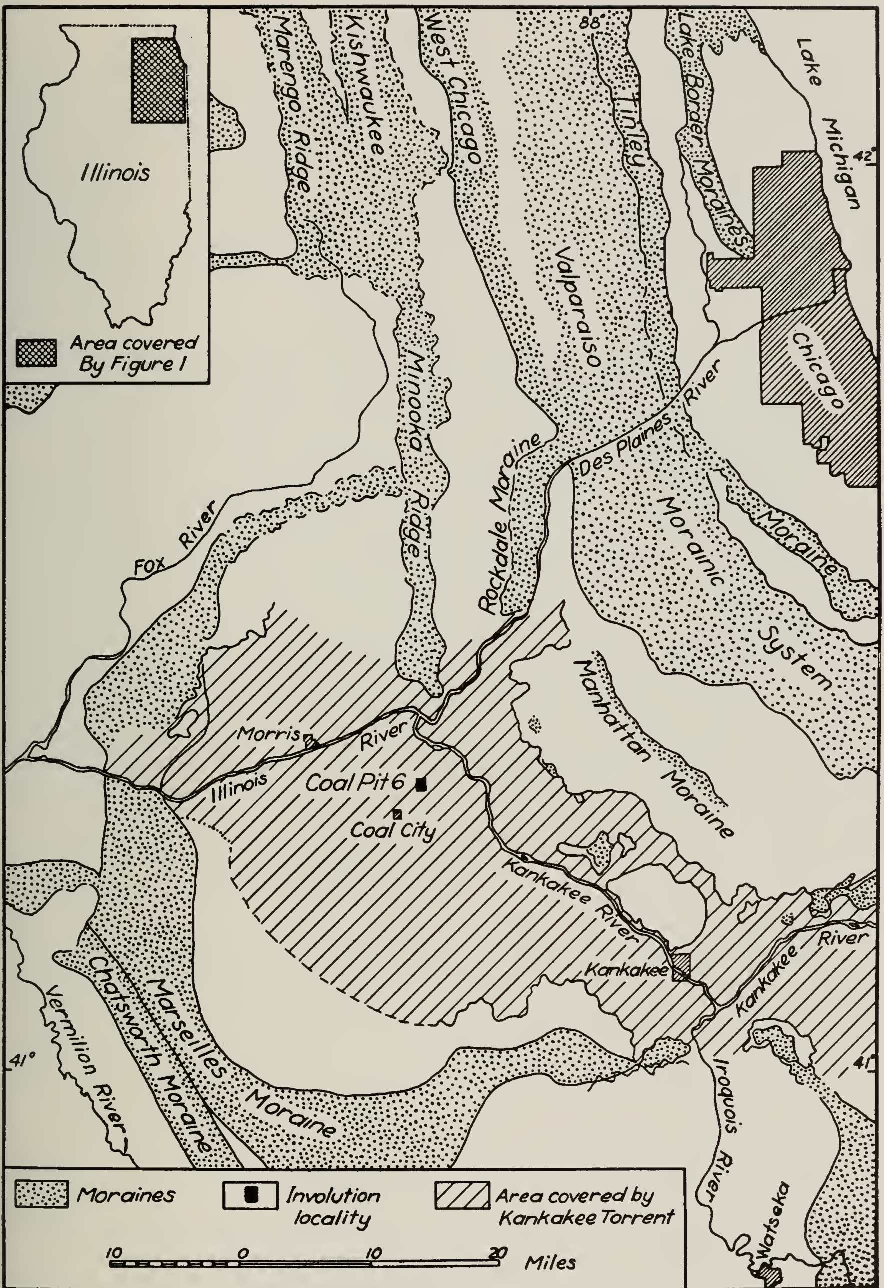

FIG. 1.—Map of involution locality, moraines, and area covered by Kankakee torrent. Based upon published works and subject to alteration by Illinois Geological Survey reports in prepa ration or in press.

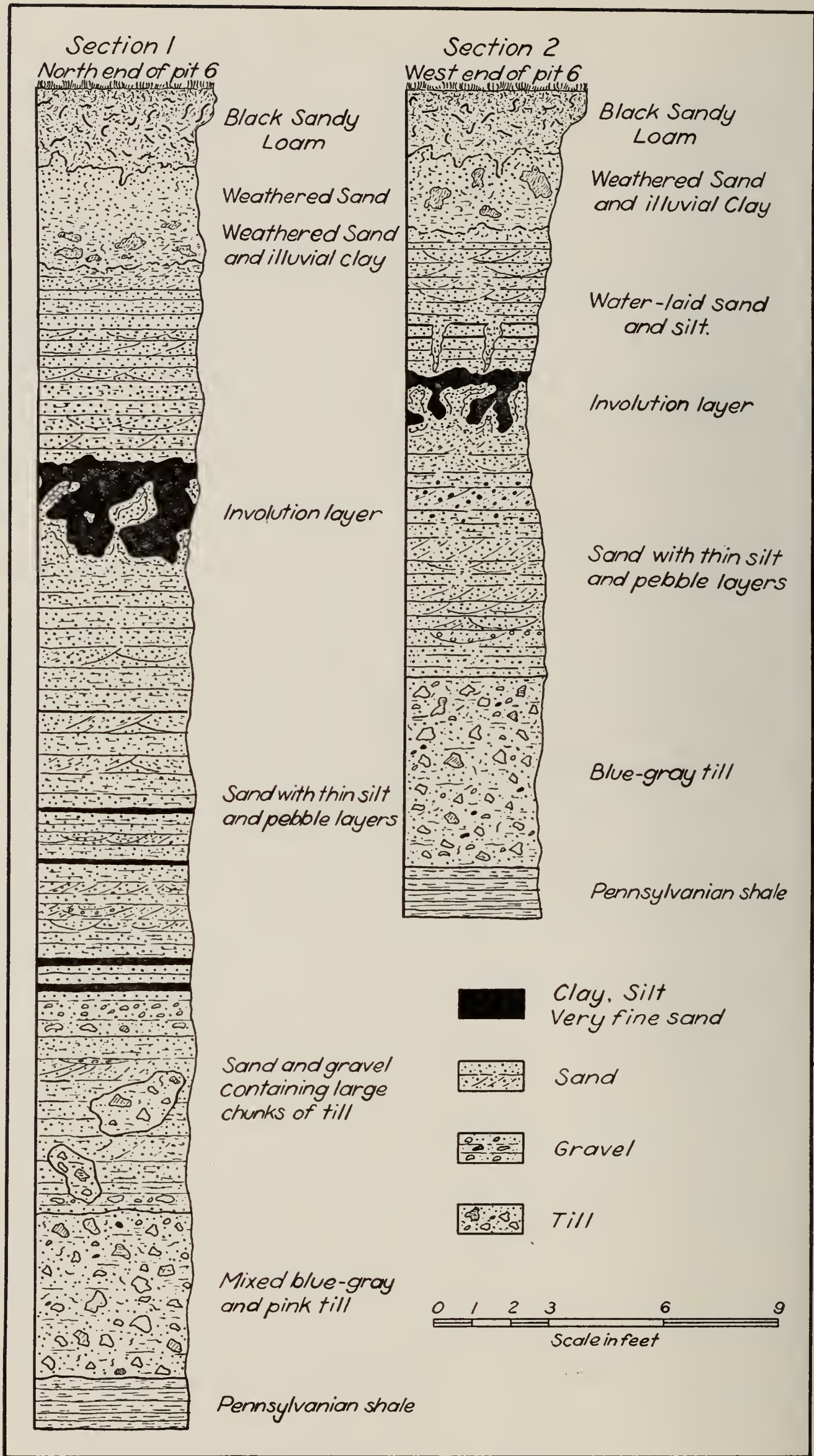

FIG. 2.—Representative sections of Pleistocene deposits at Pit 6

tent. Scour channels, cross-bedding, and foreset beds occur in nearly every exposure. The water-laid materials are probably Kankakee torrent deposits[15] of late- or slightly post-Valparaiso age (late Middle Wisconsin). They grade upward into a layer of structureless brown weathered sand which contains considerable illuvial clay, particularly toward the bottom where the clay has accumulated in irregularly distributed masses. The soil layer at the top consists of a black,

FIG. 3.—Involution layer in central part of Pit 6. Aimless interpenetration of sand and silt masses shown. Sand weathers out, leaving silt masses projecting. Maximum depth of deformation is 10 feet.

carbonaceous sandy loam containing irregularly distributed masses of clay and a maze of small plant roots. Toward the bottom it is moderately rich in illuvial clay, and the contact with the underlying sand is transitional and irregular.

INVOLUTIONS

DESCRIPTION

The involutions consist largely of intensely deformed, involved, and haphazardly interpenetrating masses of silt and sand originally arranged in horizontal beds. Masses of silt have been intruded into

[15] G. E. Ekblaw and L. F. Athy, "Glacial Kankakee Torrent in Northeastern Illinois," *Bull. Geol. Soc. Amer.*, Vol. XXXVI (1925), pp. 417–28.

the sand, which has thereby been considerably disturbed. Most abundant are the teardrop-, tenpin-, jug-, and boot-shaped masses (Figs. 4 and 5) of silt irregularly connected by thin stringers and tongues extending through the sand. Rounded or curved outlines predominate, but sharp, angular forms are not entirely lacking. Seemingly isolated nests of sand or lumps of silt are usually connected with other sand or silt masses in the third dimension. Some

FIG. 4.—Involutions at north end of Pit 6. Dark material is silt; light material is sand. Note deformation of sand near hammer. Exposure on vertical face at depth of 12 feet.

of the structures appear to be ordinary folds, irregularly compressed and associated with intrusive masses like those just described; however, these folds are sparse, discontinuous, and of limited axial extent. In general there is a notable similarity and uniformity in separate involution layers, but they vary considerably in detail.

A highly distinctive feature of the involutions is their lack of linear trend or continuity. Sections cut at right angles in the same involution layer differ only in the minor details of size, shape, and arrangement of the silt and sand masses (Fig. 6). As a vertical section

through an involution layer is cut back parallel to itself, the size, shape, and arrangement of the intrusions change constantly (cf.

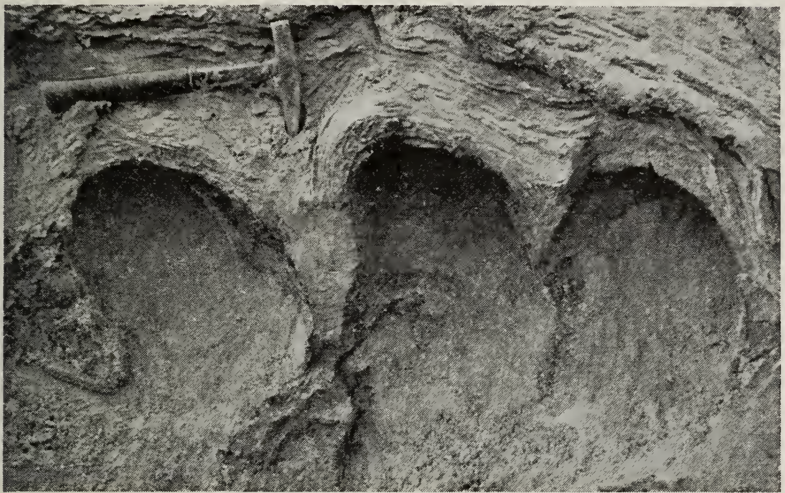

FIG. 5.—Boot-shaped intrusion of silt in sand. Lack of corresponding deformation in overlying beds indicates plasticity and migration of silt.

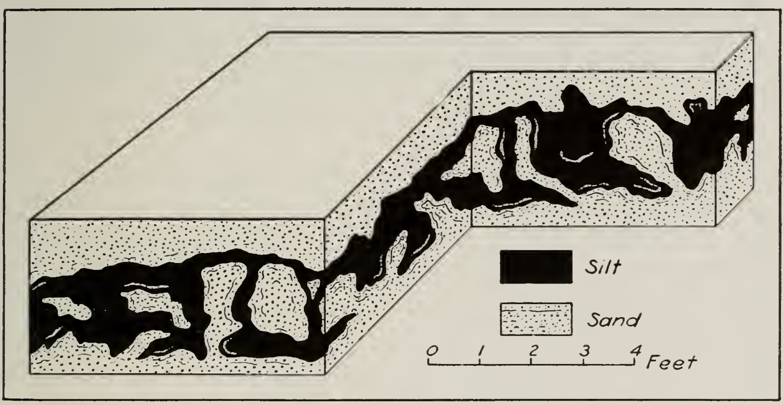

FIG. 6.—Right-angle sections in involution layer. Sketched from artificial cut made in field. Lack of linear trends or continuity of structures notable.

Figs. 7 and 8). Even seemingly ordinary folds have little axial extent and are replaced by other wholly unrelated structures. There is no evidence of the linear trend expected in structures resulting from

normal compressional deformation. Furthermore, deformation appears only in places where sand and silt are interbedded, being absent where the section consists entirely of sand.

K. Keilhack[16] has likened involutions (*Brodelböden*) to the structures produced by thrusting a blunt stick at various points into horizontally bedded plastic materials so that one bed is thrust and kneaded into another. The impression that lumps of silt have been thrust upward or downward into adjoining beds is gained from close observation of vertical sections and has been recognized by Adolf

FIG. 7.—Vertical cut in involution layer. Compare with Figure 8

Bahr[17] in his terms *Sinkmassen* and *Steigmassen*. Since horizontal or inclined sections through involution layers show somewhat similar relations, it seems likely that intrusion has occurred in all directions and not simply upward or downward. In many exposures, however, downward intrusions do predominate. Because a simple downward or upward punching of a bed is not enough to account for the size of the silt masses, considerable lateral migration of silt to form the in-

[16] "Über Brodelböden im Taldiluvium bei Senftenberg und über das Alter der sie begleitenden Torf- und Faulschlammablagerungen," *Zeitschr. deutsch. geol. Gesellsch.*, Vol. LXXIX, Monatsber. B. (1927), p. 364; "Die geologischen Verhältnisse in der Niederlausitz, mit besonderer Berücksichtigung der alten und neuen Tagebau der Ilse Bergbau-Actiengesellschaft," (privately printed, 1938), pp. 84–85.

[17] "Frostgestauchte Böden im westlichen Schleswig-Holstein," *Zeitschr. deutsch. geol. Gesellsch.*, Vol. LXXXIV (1932), p. 24.

trusions is indicated. This movement of material to centers of intrusion would account for the marked pinching and swelling of the silt beds and would help explain the relatively slight deformation of beds immediately overlying some downthrust intrusions (Fig. 5). The intense deformation in most layers also terminates downward rather abruptly, so that the underlying beds are undisturbed.

Irregularities in the soil zones consist chiefly of localized accumulations of illuvial clay and tubular or odd-shaped bodies of loam. The general appearance of these irregularities is not that of an in-

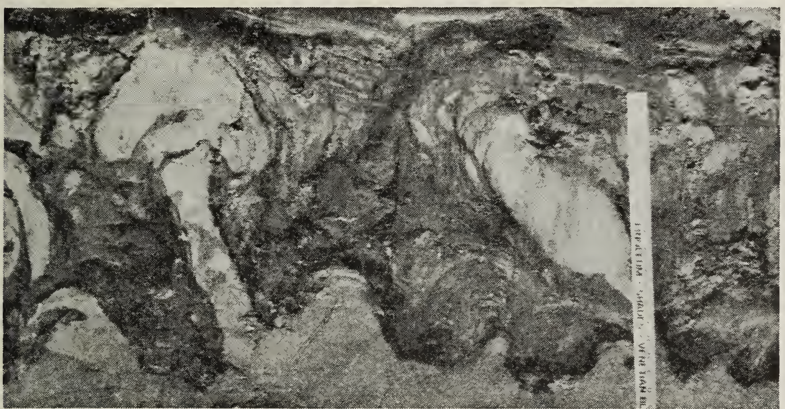

FIG. 8.—Face of same bank shown in Figure 7 cut back about 1 foot. Note changes in size, shape, and distribution of sand and silt masses.

volution layer, although possibly some of them may be remnants of a weathered involuted layer in which the secondary changes have largely obscured the earlier relations. For the most part, however, they are attributed to modern processes of weathering, minor frost heaving, and the action of organisms.

NATURE OF INVOLUTED MATERIALS

The Morris Basin involutions are limited to exposures containing at least some beds of silt or clay and are lacking in sections consisting wholly of sand. A channel sample taken from the core to the sandy rim of a silty intrusive mass consists of the following sizes of material (Wentworth grade scale) in the following percentages: 0.5 granule, 0.4 very coarse sand, 1.5 coarse sand, 12.8 medium sand, 23.7 fine

sand, 26 very fine sand, 31.3 silt (13 coarse silt, 9.5 medium silt, 6.7 fine silt, 2.1 very fine silt), and 4 clay. A sample of another silt intrusive taken from the core only contains 39.8 per cent fine and very fine sand, 49.2 silt (12.8 coarse silt, 18.3 medium silt, 12.4 fine silt, 5.7 very fine silt), and 11.4 clay. Elsewhere in the pit thin beds of the following constitution have been deformed: 2 per cent very fine sand, 32.1 silt (1.4 coarse silt, 18.5 medium silt, 12.2 fine and very fine silt), and 66 clay.

The predominance of fine and very fine sand and the various grades of silt is characteristic. The third analysis shows that at least some beds containing a large amount of clay may be deformed. The sand beds incorporated in the involutions consist of medium, fine, and very fine sand in various proportions. Pebbles up to ¼ inch in diameter have been found in the deformed material, but they are usually few and scattered, although at one place a ½-inch pebble layer was involved. In other areas involutions have been reported in gravels,[18] and gravel beds adjacent to an involuted silt lens near Watseka, Illinois,[19] have also been deformed.

INVOLUTION LAYERS

INVOLUTION LAYERS IN PIT 6

The involution layers in Pit 6 are from a few inches to 6 feet thick (Fig. 3), with an average at 2–3 feet, and in many cases have rather sharp upper and lower boundaries. The deepest involutions are 12 feet below the surface (Fig. 2, sec. 1), and most are 5–10 feet deep, although some extend to within 3 or 4 feet of the surface, where they merge with and are obscured by the lower soil zones (Fig. 3). The thickness and distribution of the deformed layers are controlled primarily by the constitution of the beds, except that beds of favorable composition below a depth of 12 feet are not deformed. Usually only one involution layer is seen in a single exposure, but in a few

[18] F. Krekeler, "Fossile Strukturböden aus der Umgebung von Giessen und Wiesbaden," *Zeitschr. deutsch. geol. Gesellsch.*, Vol. LXXXI (1929), pp. 460–61; Bahr, "Frostgestauchte Böden . . . . ," *op. cit.;* Bryan and Ray, "Geologic Antiquity . . . . ," *op. cit.*, p. 26.

[19] This locality is in a gravel pit 4½ miles northeast of Watseka on the banks of the Iroquois River (SW. ¼ Sec. 30, T. 27 N., R. 11 W.). It was called to the writer's attention in 1939 by Dr. G. E. Ekblaw of the Illinois State Geological Survey.

places where two or more groups of suitable beds exist two or more involution layers, separated by seemingly undeformed materials, have been observed. There is no indication that these separate layers were deformed at different times, although two or more involution layers of different ages in single exposures have been described from widely separated parts of Europe.[20]

INVOLUTION LAYERS IN OTHER LOCALITIES

Involution layers showing features which are almost the exact replica of those in Pit 6 have been pictured and described from many places in Europe.[21] Joshua Trimmer and Fisher,[22] Denny,[23] and Bryan and Ray[24] have described involutions from England, Connecticut, and Colorado, respectively.

Involutions have also been observed in Pit 7 of the Northern Illinois Coal Corporation, 3 miles northwest of Pit 6, and in a gravel pit 4½ miles northeast of Watseka, Illinois. The involutions at Watseka were discovered by Dr. G. E. Ekblaw. Leland Horberg has observed an older well-developed involution layer near Cambridge in Henry County, western Illinois, and near Davenport, Iowa. J. H.

[20] Ernst Becksmann, "Fossile Brodelböden im Profile des Roten Kliffs (Sylt) und damit zusammenhängende diluvialgeologische Fragen, *Neues Jahrb. f. Min., Geol., u. Paläo.*, Beilage LXVI, Abt. B (1931), pp. 440, 453, 456, 460–61; H. Breuil, "De l'importance de la solifluxion dans l'étude des terrains quaternaires du nord de la France et des pays voisins," *Rev. géog. phys. et géol. dynamique*, Vol. VII (1934), pp. 269–332; Keilhack, "Über Brodelböden im Taldiluvium . . . . ," *op. cit.*, pp. 364–65; "Die geologischen Verhältnisse in der Niederlausitz . . . . ," *op. cit.*, pp. 86–88.

[21] E. Horn, "Die geologischen Aufschlüsse des Stadtparkes in Winterhude und des Elbtunnels und ihre Bedeutung für die Geschichte der hamburger Gegend in postglazialer Zeit," *Zeitschr. deutsch. geol. Gesellsch.*, Vol. LXIV (1912), pp. 133–34; W. Wolff, "Einige glazialgeologische Probleme aus dem norddeutschen Tiefland," *Zeitschr. deutsch. geol. Gesellsch.*, Vol. LXXIX, Monatsber. B. (1927), pp. 344–45; Alfred Dücker, "Steinsohle oder Brodelpflaster," *Centralbl. f. Min., Geol., und Paläo.*, Abt. B (1933), pp. 265–66; Otto Wittmann, "Diluvialprofile mit periglazialen Erscheinungen im Donaugebiet bei Immendingen," *Jahresber. u. Mitt. der Oberrheinischen geol. Vereins*, Vol. XXV (1936), pp. 99–101, 105.

[22] Trimmer, "Generalizations Respecting the Erratic Tertiaries or Northern Drift," *Quart. Jour. Geol. Soc. London*, Vol. VII (1851), pp. 19–31; Fisher, "On the Warp (of Mr. Trimmer) . . . . ," *op. cit.*

[23] "Periglacial Phenomena . . . . ," *op. cit.*

[24] "Geologic Antiquity . . . . ," *op. cit.*, pp. 26, 61.

Lees[25] pictures and describes a deformed layer in glacial deposits in Iowa which looks like a typical involution layer, although he attributes the deformation to slumping.

ORIGIN OF INVOLUTIONS

GENERAL STATEMENT

The following agents and processes might be considered as possible participants in the formation of involutions: (1) organisms, both plants and animals;[26] (2) earthquakes; (3) springs;[27] (4) pressed melt;[28] (5) mass movements;[29] (6) convection currents; (7) ice shove; (8) differential loading; (9) repeated differential freezing and thawing and development of masses of ground ice. The particular physical and geological relations at the coal pit appear to eliminate the first five items from further consideration, although it must be admitted that at least some of them can cause involution-like deformation under proper conditions.

CAUSES OF DEFORMATION

Convection currents.—A. R. Low[30] has suggested that soil structures in Spitzbergen and elsewhere may have been formed by convection currents set up by the difference in density of water at 0° and 4° C. Gripp[31] has adopted this explanation with some enlargements and modifications, and the feasibility of the Low-Gripp hypothesis has been the subject of an extended discussion in the foreign literature.[32]

[25] "Geology of Crawford County, Iowa," *Iowa State Geol. Surv. Ann. Rept. 1925–26*, Vol. XXXII (1927), p. 335.

[26] H. J. Lutz and F. S. Griswold, "The Influence of Tree Roots on Soil Morphology," *Amer. Jour. Sci.*, Vol. CCXXVII (1939), pp. 389–400.

[27] H. Behlen, "Eine neue Theorie der Struktur-(Steinring-, Steinnetz-, oder Brodel-) Böden," *Zeitschr. deutsch. geol. Gesellsch.*, Vol. LXXXII (1930), pp. 635–36.

[28] R. G. Carruthers, "On Northern Glacial Drifts: Some Peculiarities and Their Significance," *Quart. Jour. Geol. Soc. London*, Vol. XCV (1939), pp. 299–330.

[29] W. J. Miller, "Intraformational Corrugated Rocks," *Jour. Geol.*, Vol. XXX (1922), pp. 587–610.

[30] "Instability of Viscous Fluid Motion," *Nature*, Vol. CXV (1925), pp. 299–300.

[31] "Beiträge zur Geologie von Spitzbergen," *op. cit.*

[32] C. S. Elton, "The Nature and Origin of Soil-Polygons in Spitzbergen," *Quart. Jour. Geol. Soc. London*, Vol. LXXXIII (1927), pp. 172–73, 183–84; Hans Mortensen, "Über die physikalische Möglichkeit der 'Brodel'—Hypothese," *Centralbl. f. Min., Geol., u. Paläo.*, Abt. B (1932), pp. 417–22; Alfred Dücker, "Frostschub und Frosthe-

This theory does not seem applicable here, for it is difficult to attribute the intrusions in the involution layers to convection currents set up by the slight density difference of water at 0° and 4° C. In addition the involutions do not have the rather simple cell-like structure required by this theory.

Differential loading.—If clay or silt interbedded with sand and saturated with water were subjected to a differential overburden, the interpenetration of these materials might occur, thus producing involution-like structures.[33] The present overburden at the coal pit is notably uniform and not particularly heavy. Where the involutions extend close to the surface there is practically no superadjacent load. Three possible sources of pre-existing differential overburden may be considered briefly: (1) sand dunes, (2) overlying glacial or glaciofluvial deposits now removed, and (3) glacial ice. Low fixed dunes lie along the northern edge of the flat into which the coal pit is dug. They are built of sand from a shore or beach just to the north and have always been fixed at essentially their present position. They did not move across that part of the flat in which the involutions are exposed. There is no independent evidence of a former overburden of glacial or glaciofluvial deposits in this area, and the probability that the deformed beds are Kankakee torrent materials largely eliminates the possibility of such an overburden. An overburden of glacial ice is in somewhat the same category, for the ice had retreated nearly into the Lake Michigan basin by the time the Kankakee torrent deposits were formed, and it never re-entered the area. If differential overburden were the right explanation, involutions should be found in nonglacial and nonperiglacial areas. Furthermore, it is questionable that differential overburden could produce the small-scale complexities observed in the involutions.

Ice shove.—Deformation of unconsolidated glaciofluvial materials

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bung," *Centralbl. f. Min., Geol., u. Paläo.*, Abt. B (1933), pp. 441–45; Karl Gripp and W. G. Simon, "Experimente zum Brodelboden-Problem," *Centralbl. f. Min., Geol., u. Paläo.*, Abt. B (1933), pp. 433–40; "Nochmals zum Problem des Brodelbödens," *ibid.* (1934), pp. 283–86; Hans Poser, "Bemerkungen zum Strukturbodenproblem," *Centralbl. f. Min., Geol., u. Paläo.*, Abt. B (1934), pp. 39–45.

[33] E. M. Kindle, "Deformation of Unconsolidated Beds in Nova Scotia and Southern Ontario," *Bull. Geol. Soc. Amer.*, Vol. XXVIII (1917), pp. 326–27.

has been commonly attributed to shove by moving ice, either glaciers or bergs and floes, and this appears to be an entirely reasonable explanation in many places. The considerable areal extent of the involutions, their limitation to exposures containing beds of clay or silt, the lack of linear trend even in small details, and the intrusive relations show that they could not have been formed by the shove of floating ice masses or by glaciers. Furthermore, if a glacier occupied the coal-pit area after deposition of the water-laid beds, all evidence of that occupation has been removed, and, granting that the deformed materials are Kankakee torrent deposits, the possibility of a subsequent ice invasion can be eliminated by the known succession of geological events.

Repeated differential freezing and thawing and the formation of ground ice.—These processes acting in a surficial layer above perennially frozen ground are believed competent to produce involutions. Discussion and understanding of this hypothesis is facilitated by the following information.

1. The ground in areas peripheral to the Pleistocene continental glaciers, except for a surficial layer, was probably perennially frozen to a considerable depth as indicated by present areas of frozen ground in Siberia[34] and Alaska.[35] Perennially frozen ground below a surficial thawed zone promotes repeated fluctuations across the freezing-point in the surficial layer during certain seasons and serves to concentrate water there by preventing downward seepage and percolation. The surficial material thus becomes saturated and extremely mobile at times.

2. Annual, seasonal, and daily thawing are limited to a thin surficial layer above perennially frozen ground. Under natural conditions this layer is from only a few feet to 10 or 15 feet thick.

3. Masses of ground ice are formed in areas of perennial ground

[34] G. B. Cressey, "Frozen Ground in Siberia," *Jour. Geol.*, Vol. XLVII (1939), pp. 472–88.

[35] E. de K. Leffingwell, "Ground-Ice Wedges, the Dominant Form of Ground Ice on the North Coast of Alaska," *Jour. Geol.*, Vol. XXIII (1915), pp. 635–37; "The Canning River Region, Northern Alaska," *U.S. Geol. Surv. Prof. Paper 109* (1919), pp. 179–83; P. S. Smith, "Areal Geology of Alaska," *U.S. Geol. Surv. Prof. Paper 192* (1939), pp. 70–71; Ralph Tuck, "Origin of the Muck-Silt Deposits at Fairbanks, Alaska," *Bull. Geol. Soc. Amer.*, Vol. LI (1940), pp. 1298, 1309.

frost. The nature and origin of such ice masses have been most completely discussed by Leffingwell[36] and W. Soergel.[37] Many of these ice masses are vertically wedge shaped; but, from the descriptions of the writers cited above, it is clear that nearly as many are lenses, sills, dikes, and various irregular forms. Sizes range from small interstitial granules to masses with dimensions measured in tens of feet. Opinion holds that masses of ground ice form *in situ* under favorable relations of material, water, and temperature and that in most cases they are not buried chunks of glaciers, bergs, or floes.

4. The effect of grain size on repeated freezing and thawing is widely recognized as significant, but its exact role is not completely understood. Inhomogeneities in grain size and texture result in differential freezing and thawing, with the formation of masses of ground ice and concentration of water in certain areas. Notable frost heaving occurs only when masses of ground ice are formed, and it is known that the development of these ice masses is promoted by fine materials.[38] On freezing, clay takes up water from surrounding sandy materials, and repeated freezing and thawing concentrate water in the clay so that it eventually becomes saturated and highly plastic or fluid in the thawed state. Continuation of this process results in a segregation of water from clay to form layers of ice. Curiously enough, soft unfrozen masses of clay can and do exist adjacent to these layers of ice—a condition which may be partly explained by the fact that some of the water in the clay does not freeze readily and can be considerably undercooled. Conflicting statements have been made as to whether coarse or fine material freezes first, and it may be that under different conditions the order of freezing differs.

5. Any theory on the origin of involutions must take cognizance of the structures in the involution layers. The lack of linear trend,

[36] "Ground-Ice Wedges . . . . ," *op. cit.;* "The Canning River Region . . . . ," *op. cit.*, pp. 179–242.

[37] "Diluvial Eiskeile," *Zeitschr. deutsch. geol. Gesellsch.* Vol. LXXXVIII (1936), pp. 223–47.

[38] Stephen Taber, "Frost Heaving," *Jour. Geol.*, Vol. XXXVII (1929), pp. 428–61; "The Mechanics of Frost Heaving," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 303–17. G. Beskow, "Erdfliessen und Strukturböden der Hochgebirge im Licht der Frosthebung," *Geol. Foren. i Stockholm Forhandl.*, Vol. LII (1930), p. 622.

the complex form of the intrusive masses, and the lateral migration of clay and silt indicate that at least part of the material was plastic at the time of deformation and that the deforming forces were uniform neither in direction nor in strength.

Various soil structures have long been recognized as the product of repeated freezing and thawing, but the application of this idea to involutions is more recent. Bahr[39] has given the most complete treatment of the mechanics involved in the formation of involutions (*Brodelböden*) by freezing and thawing. According to him, involutions are formed in the surficial thawed layer above frozen ground at a time when at least part of the materials are in a plastic state. He assumes that the thawed zone refreezes differentially, with the masses of finer material freezing first and acting as centers of pressure from which the forces of expansion radiate, accompanied by changes in direction and strength as freezing progresses and as the various centers unite. The unfrozen and somewhat plastic, mushy material between the centers of freezing is squeezed and intruded into the surrounding beds. It is questionable whether the finer materials freeze first, but this need not invalidate Bahr's concept of pressure centers. Differential freezing and thawing is favored by inhomogeneities such as occur in interbedded sand, silt, and clay layers, and this is one of the reasons why involutions are so well developed in such materials.

Denny[40] has suggested that involutions of Wisconsin age in Connecticut are due to the formation of ground ice, and it is known that the growth of such ice masses does cause deformation.[41] Irregular masses of ground ice would produce structures reflecting their irregularities, and equally important with the structures produced by growth must be the deformation attendant upon melting. The gradual flowage and slumping of thawed material into spaces vacated

[39] "Frostgestauchte Böden im westlich Schleswig-Holstein," *op cit.*

[40] "Periglacial Phenomena . . . . ," *op. cit.*, p. 338.

[41] Leffingwell, "Ground-Ice Wedges . . . . ," *op. cit.*, pp. 646, 649; "The Canning River Region . . . . ," *op. cit.*, p. 298; Franz Lotze, "Über Schichtaufrichtungen an Klüften," *Zeitschr. deutsch. geol. Gesellsch.*, Vol. LXXXIV (1932), pp. 67–68; T. T. Paterson, "The Effect of Frost Action and Solifluxion around Baffin Bay and in the Cambridge District," *Quart. Jour. Geol. Soc. London*, Vol. XCVI (1940), pp. 100–106.

by melting ground ice would further complicate the forms already produced. Structures which indicate a considerable degree of lateral compression may be more directly the product of expanding ice masses than are the small-scale intrusions.

The existence of frozen ground beneath the deformed layers in the Morris Basin is indicated by the abrupt downward limit of deformation (Fig. 3) and the lack of deformation in suitably constituted beds at greater depths. In several places downward intrusions of silt end abruptly against underlying, undeformed clay or silt beds, and the lateral spreading of the intrusive mass at the contact indicates that it has been pushed with considerable force against an unyielding and hence probably frozen mass. Since surficial thawing presumably penetrated only a few feet, involution layers at a depth greater than 10–15 feet probably have been buried since they were formed.

The evidence of forceful downward intrusion cited above, the lateral movement of silt and clay to form the intrusive masses, and the experimental proof that clay does intrude sand under proper conditions of progressive freezing[42] suggest that the silt and clay masses have been the major active units and that the sand was more or less passively intruded and squeezed into odd shapes by these masses.

SUMMARY STATEMENT OF PREFERRED HYPOTHESIS

The ground in the Morris Basin was perennially frozen to a considerable depth when the Wisconsin glacier lay near by to the northeast. Repeated freezing and thawing in the surficial 5–10 feet produced some structural irregularities in those places where sand and silt or clay were interbedded and led to the development of masses of ground ice. These ice masses grew in times of extended freezing and shrank or disappeared entirely in times of thaw, producing corresponding deformation of the surrounding beds. Once definite irregularities had been introduced, differential freezing and thawing became more effective. Freezing presumably progressed from both above and below, owing to the cooling effect of the frozen ground beneath the surficial thawed layer. However, the predominance of downward intrusions in the involution layers would suggest that freezing from above was dominant. As the top and bottom zones of

[42] Taber, "Frost Heaving," *op. cit.*, p. 455.

freezing approached each other, the layer of partly frozen material between was subjected to considerable stress. Unfrozen plastic material was squeezed between frozen masses and into other unfrozen materials so that various intrusive relations were produced.

A consideration of the Pleistocene history of the upper Illinois Valley and of the climatic conditions in an area close to a continental glacier indicates that all this probably occurred when the ice lay a short distance back from the Valparaiso morainic system, perhaps at either the Tinley or the Lake Border positions or at some intermediate point (Fig. 1). This would place the ice front 30–50 miles northeast of the point where the involutions were being formed and date them as late Cary (late Middle Wisconsin).

SUMMARY

Certain beds of glaciofluvial sand, silt, and clay, presumably deposited by the Kankakee torrent, in the upper Illinois Valley are complexly deformed in a peculiar manner. Variously shaped masses of clay and silt have been intruded into sand. Teardrop-, tenpin-, jug-, and boot-shaped intrusions are common, and rounded outlines and downward intrusions predominate. Lack of linear trend or continuity is a particularly notable feature of these structures. Large-scale migration of clay, silt, and very fine sand to form the intrusive masses indicates considerable plasticity during deformation. The exact replicas of these features have been described from Europe, and similar forms have been observed elsewhere in this country. The structures are termed "involutions," and the layers of deformed beds are called "involution layers"—equivalents of the *Brodelböden* and *Brodelzonen* of German writers. These involutions are developed only where beds of clay or silt are interbedded with sand and are lacking where the section consists wholly of sand. Deformation has not been observed below a depth of 12 feet and may extend within 3 or 4 feet of the surface. Single involution layers are from a few inches to 6 feet thick and usually have rather sharp boundaries, particularly on the under side.

Consideration of a variety of possible modes of origin leads to the conclusion that these involutions are the product of vigorous and repeated differential freezing and thawing and the development

and melting of masses of ground ice. It is postulated that this occurred in a surficial layer above perennially frozen ground in an area peripheral to a glacier where periglacial (arctic) conditions prevailed. Freezing probably occurred both from above and from below owing to the underlying frozen ground, and squeezing of unfrozen plastic material between frozen masses and into other unfrozen material is suggested. All the involutions are thought to be of the same age and are believed to have been formed when the ice front lay 30–50 miles to the northeast. They are dated as late Cary (late Middle Wisconsin).

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